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LEVEL Ⅱ

RADAR TEST RANGE

CONSTRUCTION

TR 04-165-04

Prepared for

USAF SYSTEMS COMMAND
Aeronautical Systems Division
UPD-X Program Office

Prepared by

Dino Sofianos
Dave Phillips

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1.0 INTRODUCTION

The purpose of this report is to present the placement and configuration of the radar test range in Gila Bend, Arizona. The range has been designed to test the performance of the Flexible Test Bed (FTB) digital processor. The methodology and conceptual design of the radar test range are presented in a previous report [1].

The construction of the radar test range was done by Dino Sofianos (SAI) and Dave Phillips (SAI) from April 1, 1980 through April 6, 1980.* Construction of the radar range included locating appropriate test sites, installing the reflectors and obtaining ground truth data.

Four separate radar range sites were constructed in order to optimize each site for a particular set of measurements. The radar test sites were named after the particular image quality parameters to be measured. The four radar range sites constructed were:

(1) Calibration,
(2) Linear,
(3) Non-linear, AND
(4) Clutter-to-noise.

Each will be discussed in further detail in subsequent sections.

The report is organized as follows:

- Section 2 describes the placement philosophy used in the construction of the radar test range.
- Section 3 outlines the performance characteristics of the triangular trihedral corner reflectors used for the specular point targets.
- Section 4 defines the layout of each of the four separate test arrays.

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*The radar test range was inspected on July 1, 1980 and found to be in satisfactory condition.

2.0   PLACEMENT PHILOSOPHY

A previous report [1] outlined the preferred criteria for select-
ing the site of a radar test range. Of the two sites considered, the Air
Force Gila Bend East Tac range (Fig. 2-1) was selected for the installation
of the Radar Test Range for the following reasons:

1) The East Tac range is a secure area owned by the Air
    Force, reducing the opportunities for vandalism of
    the reflectors.

2) The area has been previously imaged with the FTB pre-
    decessor, which identified no-return and minimum ground
    clutter areas, along with stray targets which could
    interfere with test runs.

3) The proposed flight path lies 30 miles from the Goodyear
    Aerospace Corporation (GAC) facilities allowing use of
    the FTB for the ground receiver of the data link. This
    situation permits real-time exercise of the FTB.

4) The East Tac range has no-return regions of sufficient size
    for the clutter-to-noise measurements, as well as hill-
    sides on which to place reflectors in order to minimize
    ground bounce.

A primary consideration for selecting the location of the four test
arrays was arranging them to be imaged during a single pass of the radar.
This eliminates performance and processing differences that occur in com-
paring the results of two or more passes. In addition, it was important
that the linear array be imaged first during the pass before the radar was
saturated by the non-linear array; saturation could mask the weaker targets.

It was necessary, therefore, to select a swath that simultaneously
met the requirement for each of the four arrays. By referencing the radar
imagery provided by GAC, the swath containing the airfield and one of the
western peaks of the Sand Tank Mountains was chosen (Fig. 2-2). It was dis-
covered that a rotation of the flight path by a few degrees would put it

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FIG 2-1 AIRCRAFT MAP ILLUSTRATING LOCATION OF EAST TAC RANGE

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perpendicular to magnetic north, thereby allowing easy repeatability of pointing from reflector to reflector with a simple compass. Because of the 2½ mile minimum width of the swath, this rotation did not interfere with keeping all the arrays within a single pass. The proposed flight path is a heading 90° east of magnetic north, with the radar flying between 10 to 20 nautical miles north of the swath center line.

The particular ground swath chosen presented good locations for each of the arrays. The large, cleared area of the airfield poses a low-clutter background for the linear and calibration arrays, while the tall, jagged peaks of the mountain cause an easily recognized radar shadow for installation of the clutter array. One compromise was placing the non-linear array between the linear and clutter ranges, rather than last as was proposed. The reordering was necessary because the next suitable area would have been off the East Tac range on the eastern side of the Sand Tank Mountains, posing access and security problems. Instead, a large distance was left on either side of the non-linear array to allow for recovery of the radar. Access to all arrays except clutter is easy via existing roads on the East Tac range, and access to the clutter array is possible via a dry wash.

The mock airfield located due north of Quail Hill is an area of several acres which has been cleared of desert vegetation so that only short grasses grow there today. This provides a uniform low-clutter background for the calibration and linear arrays. The airstrip and roads are graded dirt.

2.1   CALIBRATION ARRAY

The first array to be imaged will be the four calibration reflectors. Instructions from the Air Force were to avoid the center of the airfield so as to keep the reflectors out of the way of cleanup and normal maintenance operations. For this reason the southern edge of a north-pointing triangular area of land northeast of the airstrip was selected for placement of the calibration array (Fig. 2-2). There was sufficient

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cleared area to minimize clutter from vegetation that might obscure the small corner reflectors of this array (Photograph 2-1).

Photograph 2-1 Calibration Array

2.2   LINEAR ARRAY

The linear range was placed in a clearing to the west of the airstrip, with one leg pointing northwest and the other northeast. The topographic map (Fig. 2-3) shows the approximate position of this array on the airfield. Again, the reflectors are aligned 45° from the flight path with respect to each other to avoid sidelobe contamination of the mainlobes.
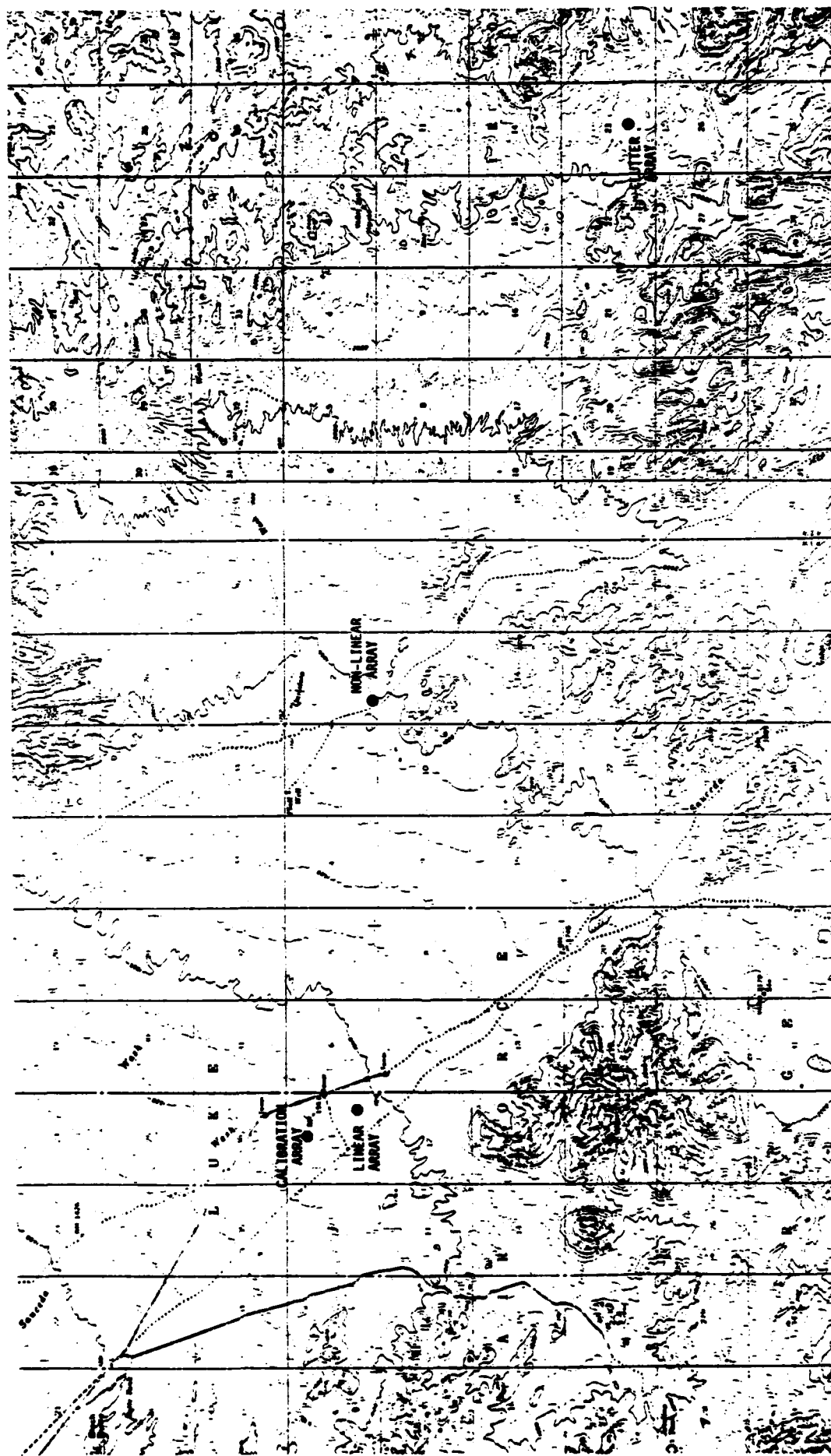
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FIG. 2-3 TOPOGRAPHIC MAP OF EAST TAC RANGE

For purposes of image contrast measurements, a uniform ground clutter background was necessary for these first two arrays. The site selected was very flat and cleared of brush (Photograph 2-2). There was not a uniform low-return area available with slopes on which to mount the reflectors, it was decided to keep the reflectors level, which reduces ground bounce interference at the expense of a loss in returned signal.
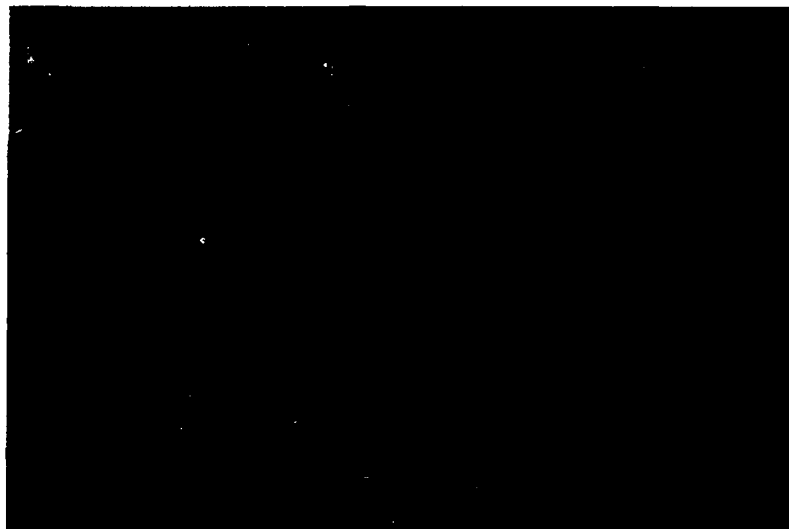

Photograph 2-2 Terrain of Linear Array with Convoy

2.3   NON-LINEAR ARRAY

The non-linear array will be the next one imaged after the linear range during a flight. A suitable location existed near some hills about midway between the airfield and the Sand Tank Mountains to the east (Fig. 2-3). Suitable distance, necessary for the saturation effects of the large reflectors on the radar to abate, is available before imaging of the clutter array is started.

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The terrain in this area had a gradual downward slope to the north which was used to advantage to minimize ground reflections. This vegetation is typical Sonoran desert type with creosote bushes predominating (Photograph 2-3). These have a typical height of about 3 feet. Care was taken in placement of the reflectors so that no obstructions would be encountered above the minimum expected grazing angle (approximately 10 degrees). The proximity of the hills is not expected to pose problems with masking the reflectors, judging from the images of past flights.
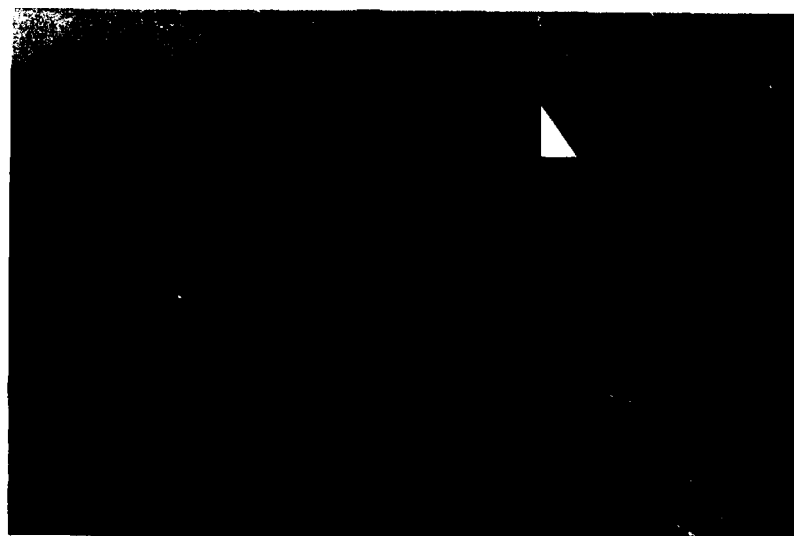

Photograph 2-3 Non-Linear Array Reflector

2.4   CLUTTER-TO-NOISE ARRAY

The clutter-to-noise array requires a distinct no-return region so it was important to place this array near a radar shadow. Consulting

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the previous imagery of the area (Fig. 2-2), one of the taller peaks in the Sand Tank Mountains produced a suitable shadow. Being extremely craggy, the mountain is an easily recognizable radar signature which should aid in finding the clutter array on the FTB imagery. While the Air Force has not cut any roads into this area, there is a wash which enabled access by 4-wheel drive vehicle.

The terrain at this location (Fig. 2-3) was hilly as with the non-linear array, so the clutter reflectors were placed on the north-facing slopes to minimize ground reflections. Because of the inability to determine exactly where the shadow would lie (there is uncertainty of the exact flight path and of the position of the clutter array), three reflectors were installed with a wide spacing. They were placed as close to the anticipated shadow as was consistent with the positioning techniques used, in order to aid data reduction from the FTB imagery. It is expected that all three reflectors will be found closely adjacent to the shadow, but in any event, the outer one will not be hidden. The reflectors were aligned, as before, at a 45° angle from the flight path for sidelobe identification. They point toward magnetic north and are mounted level on posts.

Since the clutter array was installed near mountains, the rainfall at the site is somewhat higher than on the desert floor, causing substantial differences in the natural vegetation. Present are scrubby palo verde and mesquite trees (about 15 feet high) and many large saguaro cacti (Photograph 2-4). While care was exercised to prevent obscuring the reflectors with the vegetation, the heavier growth should alter the quality of the background clutter with respect to the other sites.
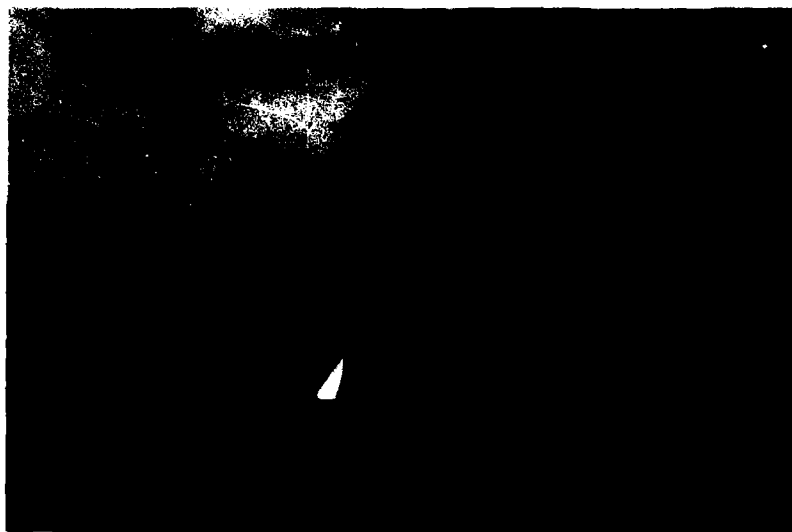
Photograph 2-4 Terrain of Clutter Array

2.5   TERRAIN OF EAST TAC

The Air Force East Tac Range consists primarily of a desert valley
floor ringed by mountains rising one to two thousand feet above it. The
valley is criss-crossed with washes which should be readily visible in the
FTB imagery and should provide aid in identifying particular locations.

To assess the particular characteristics of the terrain of this
area, photographs were taken in the four major compass point directions
from one of the small hills near the non-linear array. In each of the suc-
ceeding photographs, the vertical pole indicates the compass direction named.

Photograph 2-5 was taken north showing the northern part of the
Sand Tank Range (Slag Mountain) and the desert in the area of Platt's Well.
The next photograph (Photograph 2-6) is to the east showing the clutter
peak, to the immediate right of the pole in the far distance, and the area
of the non-linear area (across the road in the center left of the picture).
To the south (Photograph 2-7) the Sauceda Mountains may be seen in the dis-
tance. The hill in the center is approximately one-half mile distant.

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Photograph 2-5   East Tac Range - North

Photograph 2-6   East Tac Range - East

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Photograph 2-7 East Tac Range - South

One final photograph (Photograph 2-8) was taken to the west and depicts the desert area containing the airfield and the calibration and linear arrays. These are located in the far distance at what appears as a light band at the base of the mountains just to the left of the post. Quail Hill is one of the dark peaks to the left of center.


Photograph 2-8 East Tac Range - West

3.0   DESCRIPTION OF REFLECTORS

Triangular trihedral corner reflectors are used for the specular point targets in the radar test range. The operational characteristics of a triangular trihedral corner reflector are covered in a previous report by Sofianos [1], so only a brief performance summary will be given in this report.

3.1   TRIANGULAR TRIHEDRAL CORNER REFLECTOR DESCRIPTION

A line drawing of an ideal triangular trihedral corner reflector is shown in Fig. 3-1. A typical 1000 ft^2 (radar cross-sectional area) triangular corner reflector mounted on its post is illustrated in Photograph 3-1. For mounting of all reflectors smaller than 32,000 ft^2 cross-sectional area, wooden 4x4's were buried 2 feet in the ground, leaving a 4 foot platform for elevating the reflectors above the vegetation. The reflectors, made of sheet aluminum with riveted seams, were attached on one side to plywood support panels. After the posts were leveled, the reflectors were aimed and securely nailed through the plywood to the posts.
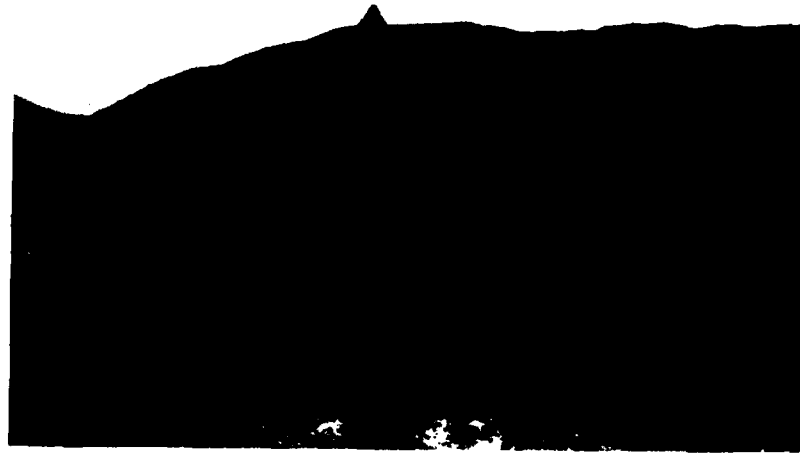
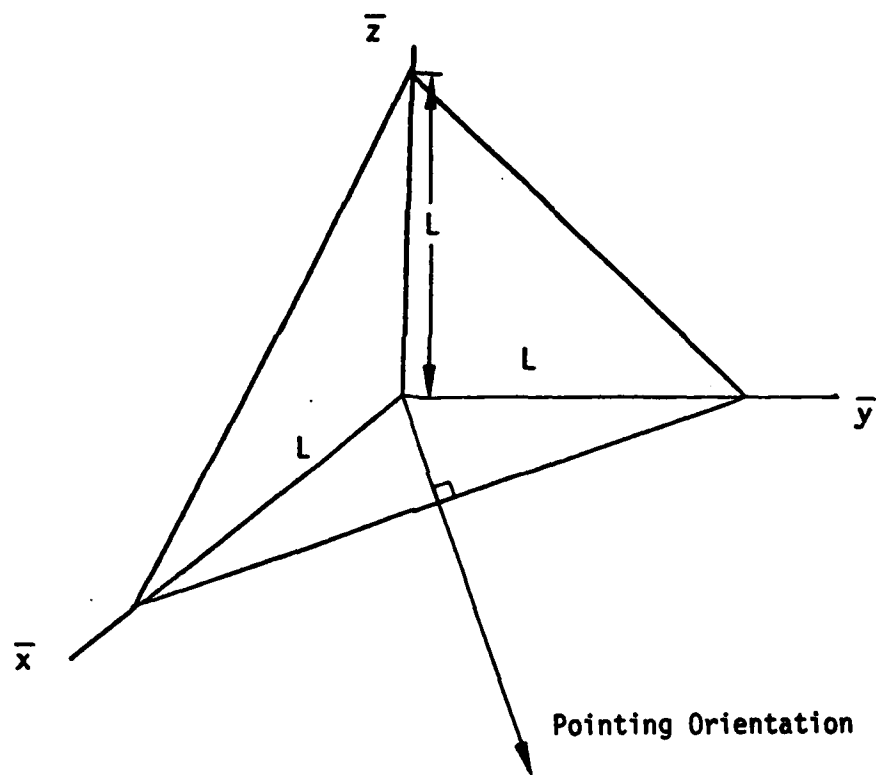Photograph 3-1   Typical 1000 Ft^2 Triangular Trihedral Corner Reflector

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Figure 3-1   An Ideal Triangular Trihedral Corner Reflector

The larger reflectors (greater than 10,000 ft^2 radar cross-sectional area) have a large wind cross-section which would have caused their destruction in just a few days had they been mounted on posts in the manner described previously. Instead, they were leveled on the earth, wedged in place with wooden stakes, and three guy lines were fastened from the top to additional wooden stakes spaced at 120^0 intervals about 2 feet from the reflector base (Photograph 3-2). The guying material was several lengths of durable hemp cord so as not to electrically interfere with the reflectors. This configuration, while not permanent, is expected to last the duration of the experiment.

Photograph 3-2 Typical 100,00 Ft^2 Triangular
Trihedral Corner Reflector

3.2   TRIANGULAR TRIHEDRAL CORNER REFLECTOR RADAR CHARACTERISTICS

The radar cross-sectional area of the triangular trihedral corner reflectors used in the construction of the radar test range spanned from 100 ft^2 to 100,000 ft^2. From Sofianos [1], the maximum cross-sectional

area σ_{max} of a triangular trihedral reflector as a function of grazing angle (Ψ) is

$$\sigma_{max}(\Psi) = \frac{4\pi L^4}{\lambda^2}\left[\sin(\Psi) + \sqrt{2}\ \cos(\Psi) - \frac{2}{\sin(\Psi) + \sqrt{2}\ \cos(\Psi)}\right]^2$$

for $15^{\circ} \leq \Psi \leq 55^{\circ}$

where   L is the length,

λ is the wavelength of the imaging radar.

A nominal wavelength of 0.1 ft will be assumed for all further calculations.

In Fig. 3-2, the normalized radar cross-section is plotted as a function of grazing angle for a triangular trihedral corner reflector. Note that the maximum cross-sectional area occurs for a grazing angle of 35.3°.

From Fig. 3-2, it is apparent that the loss in cross-sectional area can be substantial for particular grazing angles. The loss in cross-sectional area should be taken into account when the actual σ of each re-flector is required (i.e., dynamic range and calibration measurements). If the grazing angle is not known, it can be found using Fig. 3-3. In Fig. 3-3 the grazing angle is plotted as a function of radar altitude and ground range of the target.

The triangular trihedral corner reflectors used in the radar test range deviated considerably from their stated sizes. In an attempt to reduce the error associated with the non-uniform sizing of each reflector, their lengths were recorded and were used in computing their respective maximum cross-sectional area, σ_{max}. A listing of all the reflectors used in the radar test range are outlined in Table 3-1. Included in this table are the measured lengths and computed cross-sectional area of each corner reflector.
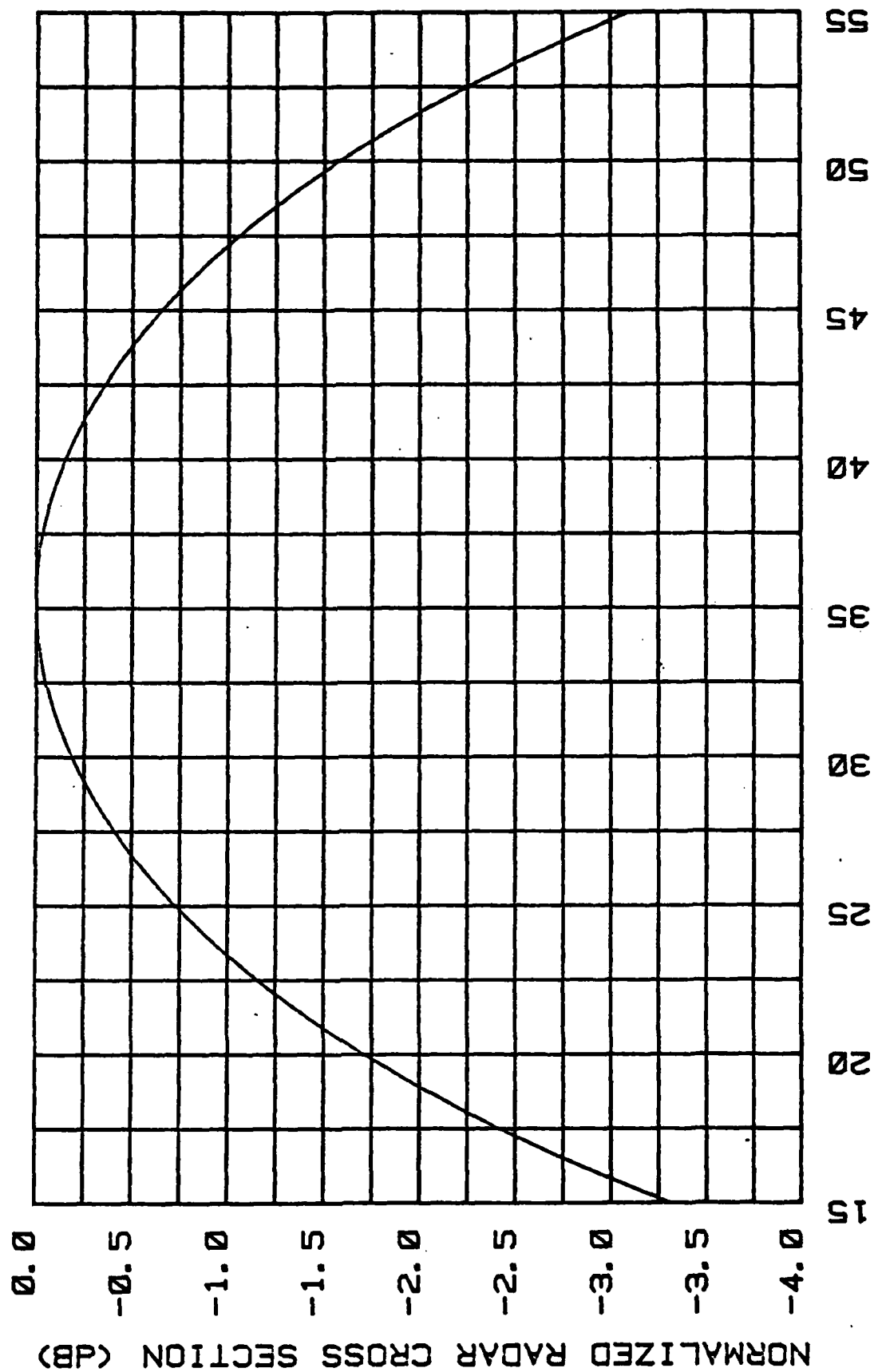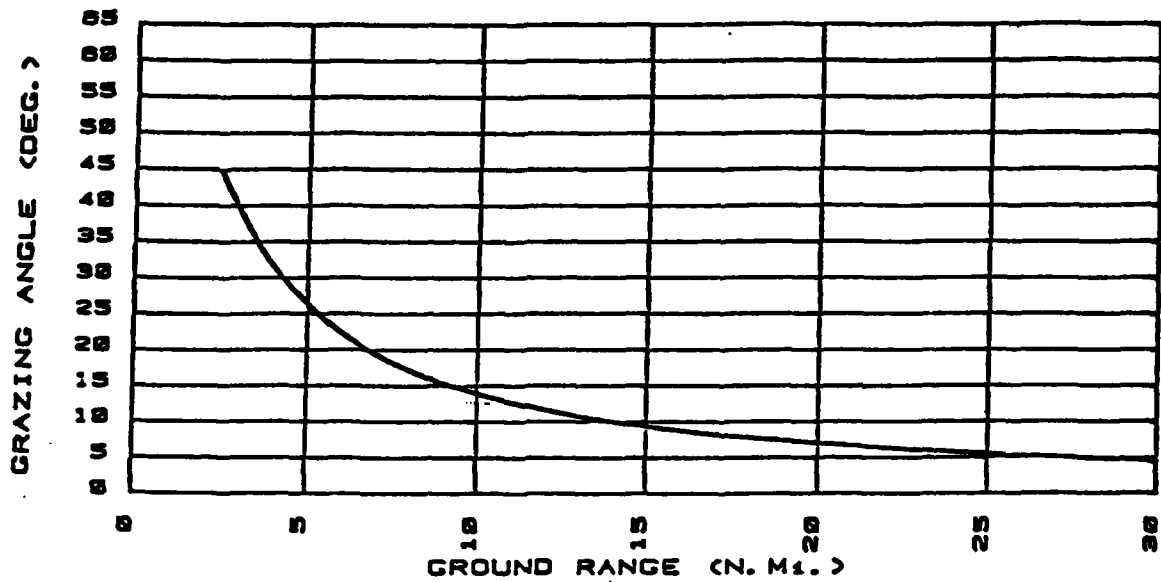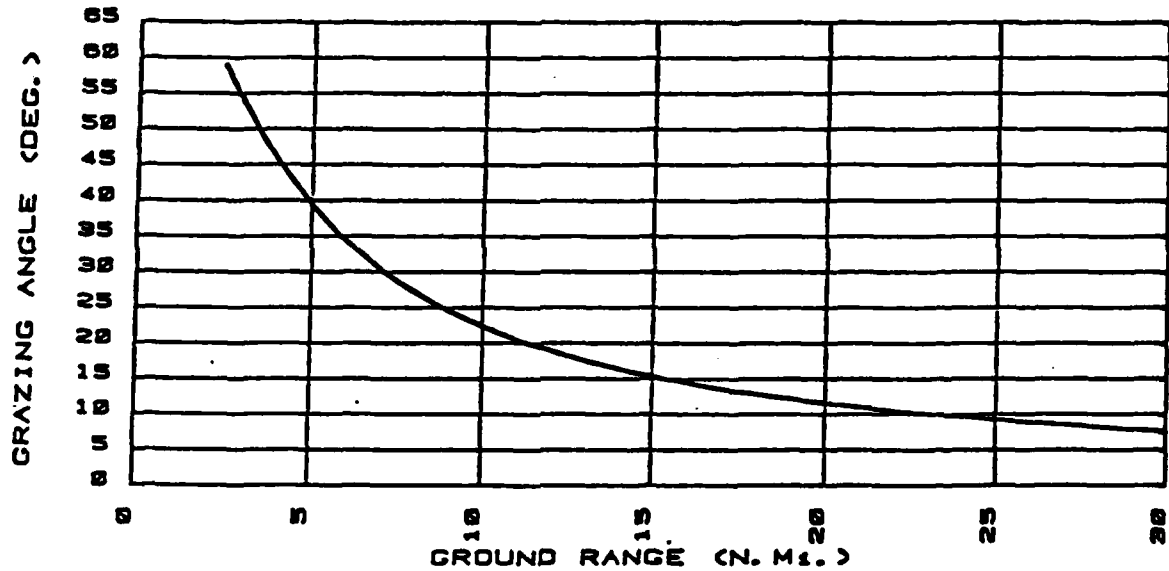
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Figure 3-2 Normalized Radar Cross Section vs. Grazing Angle for a Triangular Trihedral Corner Reflector

Figure 3-3 GRAZING ANGLE VS. GROUND RANGE

RADAR ALTITUDE- 15000 feet

RADAR ALTITUDE- 25000 feet

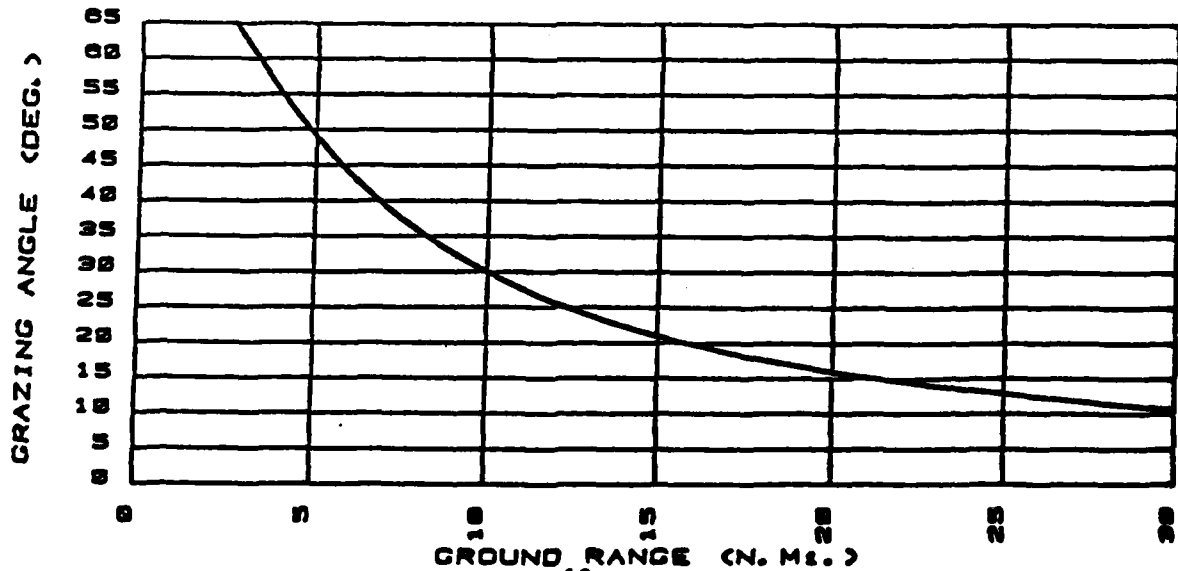

RADAR ALTITUDE- 35000 feet

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TABLE 3-1 - TRIANGULAR TRIHEDRAL CORNER REFLECTOR LISTING

REFLECTOR #	STATED σ_{max} (ft^2)	MEASURED LENGTH (L) (in.)	COMPUTED σ_{max} (ft^2)
1	3,000	19.0	2,630
2	3,000	20.0	3,230
3	1,000	15.5	1,170
4	100,000	44.0	75,700
5	1,000	15.5	1,170
6	32,000	37.5	39,950
7	1,000	15.5	1,170
8	1,000	15.5	1,170
9	1,000	15.5	1,170
10	1,000	15.5	1,170
11	1,000	15.5	1,170
12	100	7.0	49
13	1,000	15.5	1,170
14	10,000	28.75	13,800
15	320	11.25	320
16	3,200	20.0	3,230

4.0   CONFIGURATION OF THE TEST ARRAYS

In a previous report by Sofianos [1], a radar range test range was designed using three radar test arrays. Not included in that report was a fourth radar test site, a calibration site, which was added since a calibrated Luneberg lens reflector was unavailable.

In this section, the layouts of the individual sites are given including orientation, sizes, and distances between the reflectors. Section 4.1 covers the calibration array, Section 4.2 the linear array, Section 4.3 the non-linear array and Section 4.4 the clutter-to-noise (C/N) array.
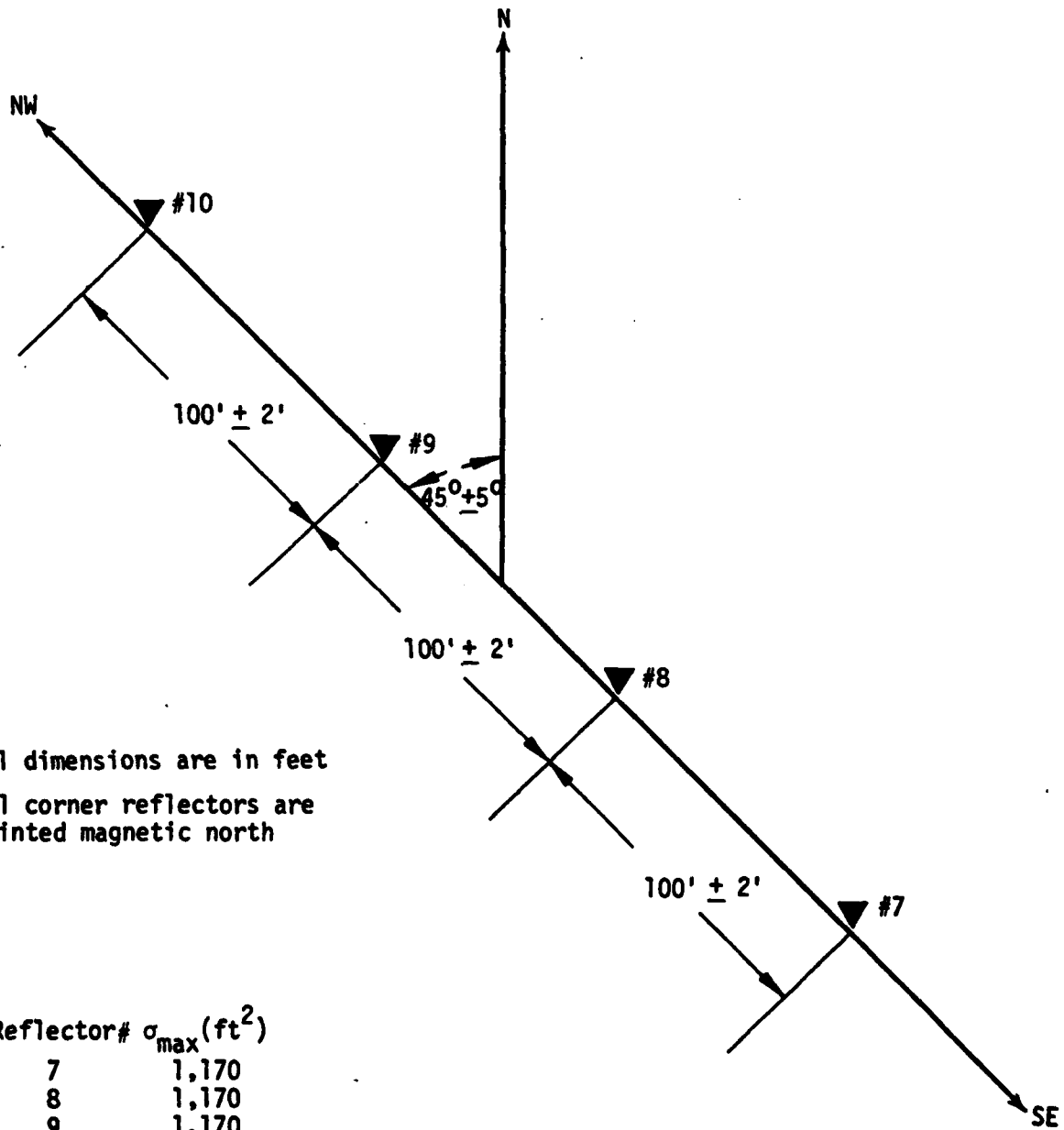
4.1   CALIBRATION ARRAY CONFIGURATION

A calibrated radar test site was constructed to be used as a reference for cross-sectional area measurements. Sofianos [1] had recommended using a Luneberg lens reflector for the calibrated reference source. Since a Luneberg lens was unavailable, four reflectors with the same radar cross-sectional area were used. By averaging the measured radar cross-sectional area of each they can be used as a calibrated reference source. The configuration of the calibrated site is illustrated in Fig. 4-1. Photograph 4-1 is included to show the alignment of the four 1000 ft^2 corner reflectors and surrounding ground terrain.

Photograph 4-1 Calibration Array

FIG 4-1   CALIBRATION ARRAY

NOTES:

1. All dimensions are in feet

2. All corner reflectors are pointed magnetic north

Reflector#	$\sigma_{max}(ft^2)$
7	1,170
8	1,170
9	1,170
10	1,170

N

NW

SE

#10

$100' \pm 2'$

#9

$45^{\circ} \pm 5^{\circ}$

$100' \pm 2'$

#8

$100' \pm 2'$

#7

4.2   LINEAR ARRAY CONFIGURATION

The purpose of the linear array is to measure the IPR width, peak sidelobe level and dynamic range of the digital processor when the radar is operating linearly (i.e., not saturated). The linear array is composed of six triangular trihedral corner reflectors oriented such that their mutual interference is minimal. The reflector cross-sectional areas spans 100 ft^2 to 10,000 ft^2 in approximately 5dB increments.

The configuration of the linear array is shown in Fig. 4-2. Illustrated in Fig. 4-2 are the location of the corner reflectors and the approximate location of the surrounding spurious reflectors (i.e., convoy trucks, artillery pieces, etc.). Photograph 4-2 was taken from corner re-reflector #16 to illustrate the line of convoy trucks north of the linear array. The parabolic dish and convoy truck which are south-west of the linear range are illustrated in Photograph 4-3.
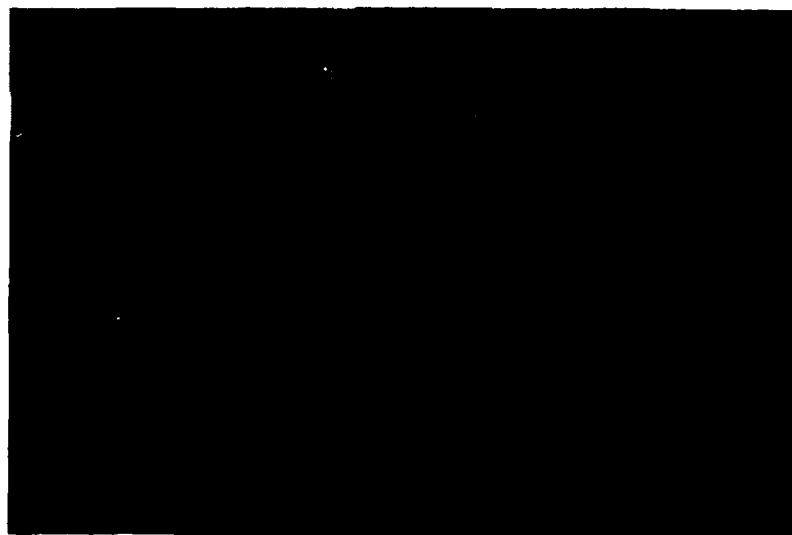
Photograph 4-2 Convoy Trucks North of Linear Array

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FIG 4-2 LINEAR ARRAY

Reflector #	σ_{max}(ft^2)
11	1,170
12	49
13	1,170
14	13,800
15	320
16	3,230
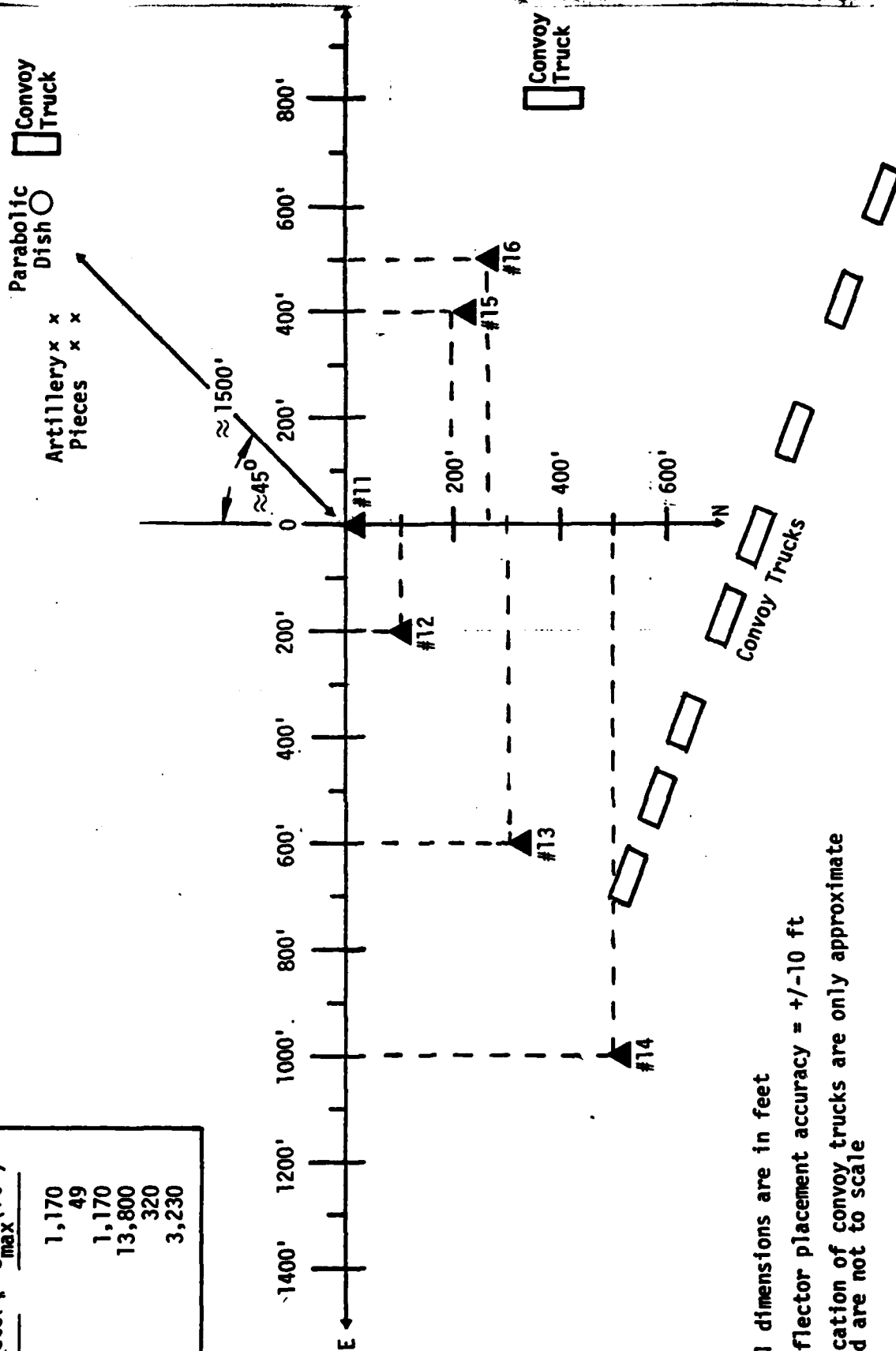
Notes:

1. All dimensions are in feet

2. Reflector placement accuracy = +/-10 ft

3. Location of convoy trucks are only approximate and are not to scale

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Photograph 4-3   Parabolic Dish and Convoy Truck
South of Linear Array

4.3   NON-LINEAR ARRAY CONFIGURATION

The purpose of the non-linear array is to determine the maximum cross-sectional area that can be viewed linearly prior to saturation. A 3.2×10^4 ft^2 and a 1×10^5 ft^2 corner reflector were used to drive the processor into a non-linear mode. A 1000 ft^2 corner reflector was placed between the two larger reflectors in order to view intermodulation effects caused by the non-linear operation of the processor while in saturation. The configuration of the non-linear array is shown in Fig. 4-3. Photographs 4-4 and 4-5 were taken looking north and south, respectively, from the 1000 ft^2 corner reflector #5. Photograph 4-6 illustrates the surrounding terrain around the 1×10^5 ft^2 corner reflector #4.
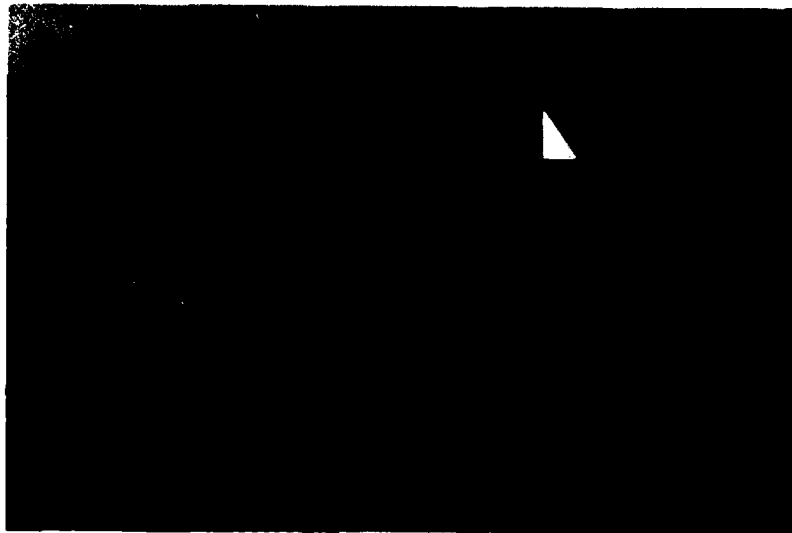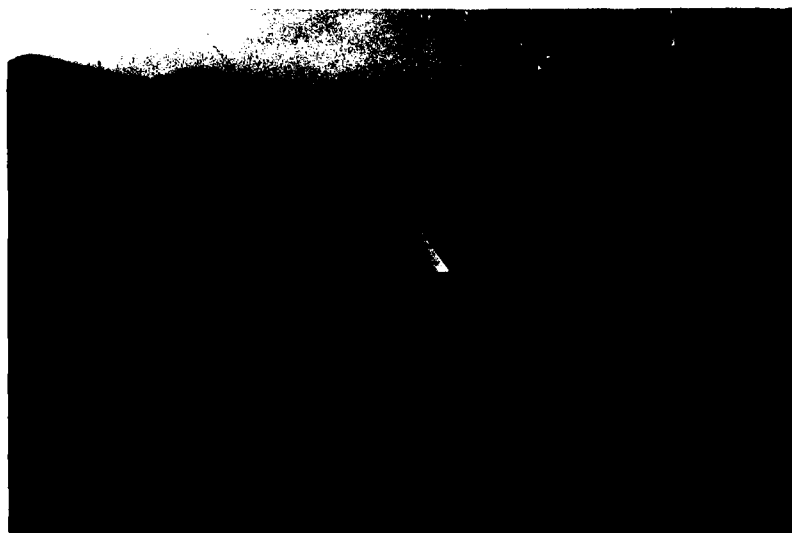
FIG 4-3 NON-LINEAR ARRAY
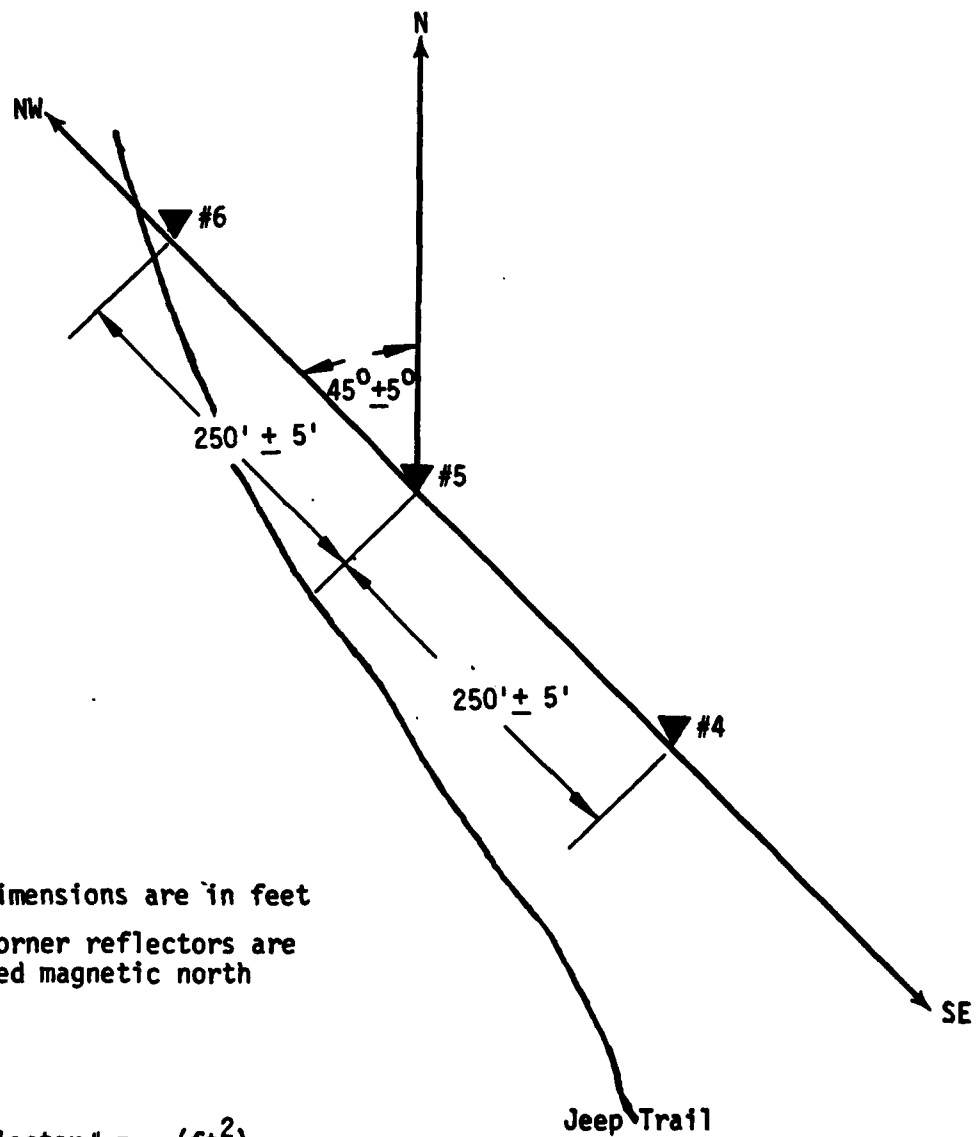
NOTES:

1. All dimensions are in feet

2. All corner reflectors are
    pointed magnetic north

Reflector#	$\sigma_{max}(ft^2)$
4	75,700
5	1,170
6	39,950

Photograph 4-4 Looking North From Reflector #5

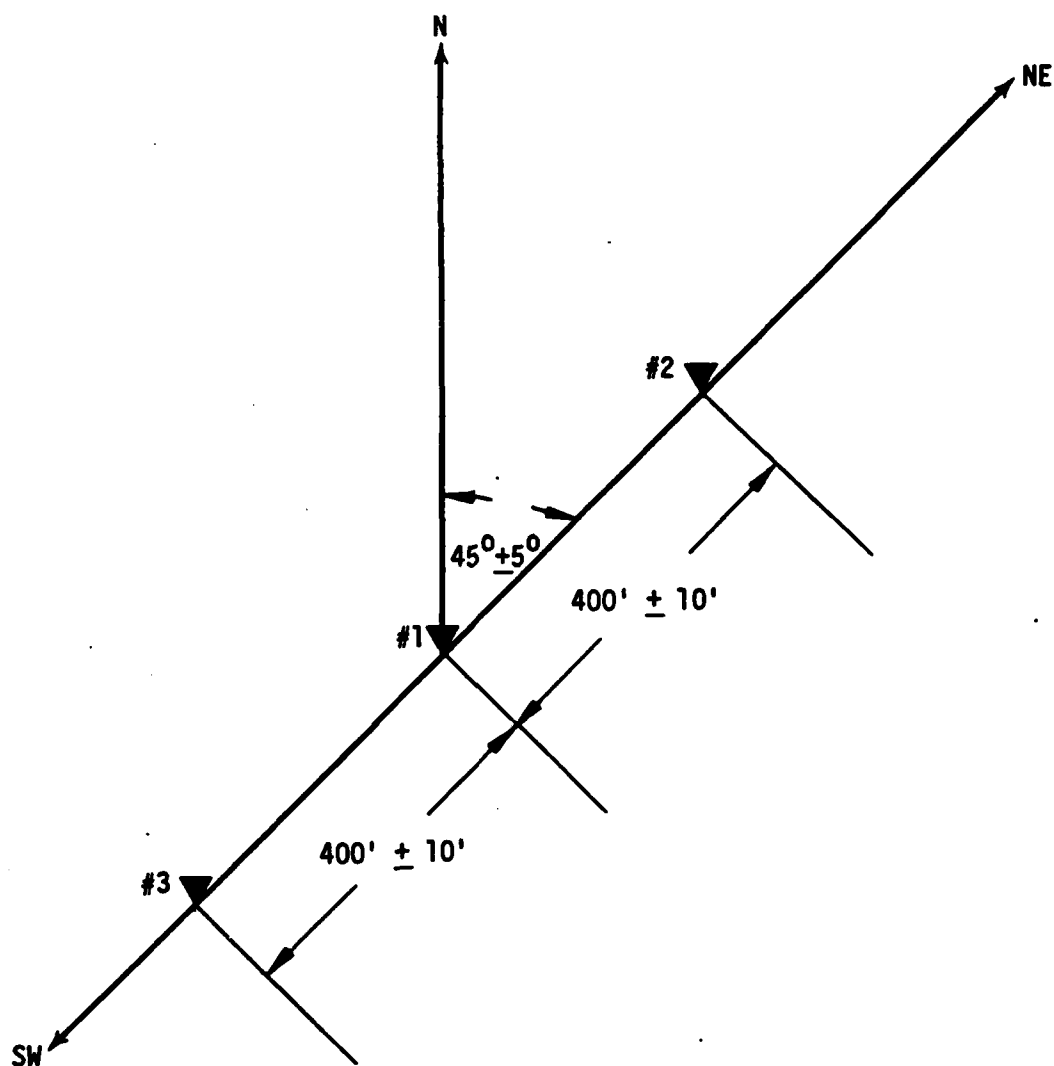Photograph 4-5 Looking South From Reflector #5

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Photograph 4-6   100,00 Ft^2 Reflector In
Non-Linear Array

4.4   CLUTTER-TO-NOISE SITE CONFIGURATION

The corner reflectors in the clutter-to-noise (C/N) site are lo-
cated near a large shadow (no-return) area. Three reflectors were set up
to assure at least one of the reflectors would be visible over a wide range
of grazing angles (i.e., flight paths). The configuration of the C/N array
is illustrated in Fig. 4-4. Photograph 4-7 illustrates the mountain range
of reflector #3 which casts the shadow area near the C/N array. The sur-
rounding terrain and alignment of the three reflectors is illustrated in
Photograph 4-8.

FIG 4-4 CLUTTER-TO-NOISE MEASUREMENT ARRAY

N

NE

#2

45°±5°

400' ± 10'

#1

400' ± 10'

#3

SW

NOTES:

1. All dimensions are in feet
2. All corner reflectors are
   pointed magnetic north

Photograph 4-7 Looking North of Clutter-To-Noise Array

Photograph 4-8 Looking Northeast From Reflector #3
In Clutter-To-Noise Array

REFERENCES

1. Sofianos, Dino, "Radar Test Range Design Considerations",
   TR 04-165-3, available from Defense Technical Information Center,
   Cameron Station, VA.

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Mapping Radar
4 Ranges (Facilities)
5 Radar Equipment Reflectors

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents construction of a synthetic aperture
radar (SAR) test range.

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